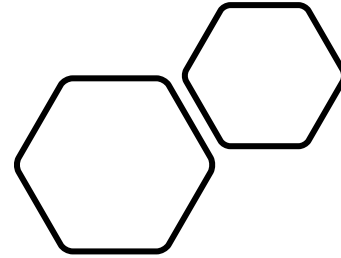


# The Virtual Observatory

EXOHOST workshop presentation  
(March 2024)

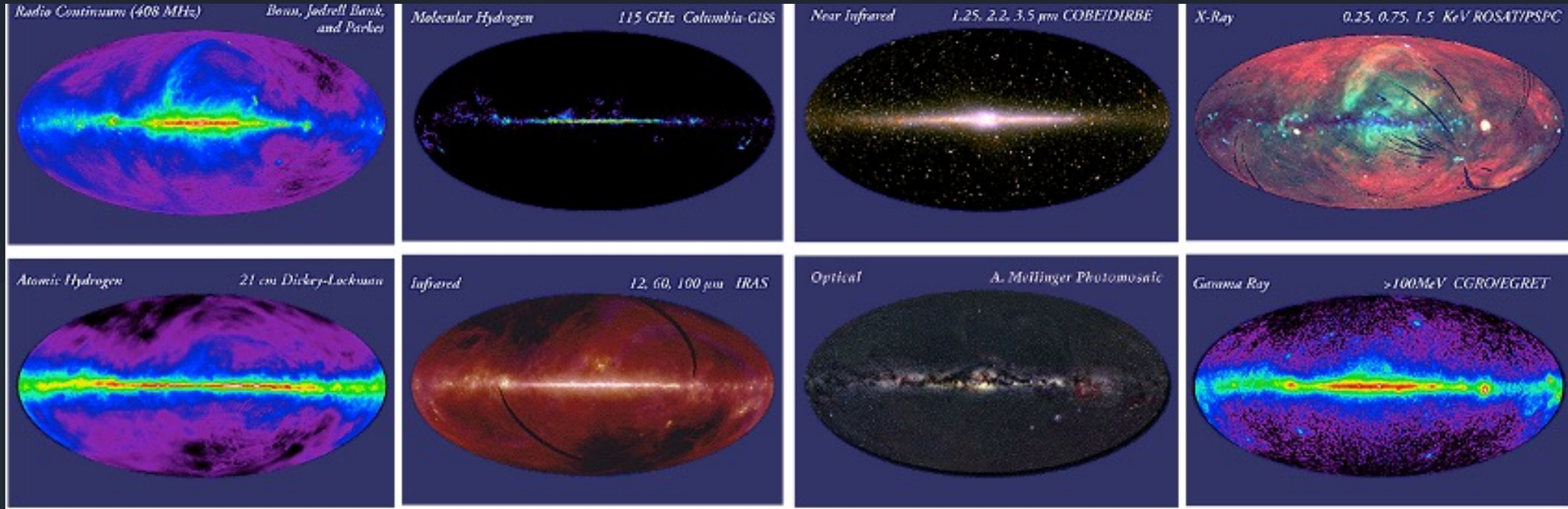
<https://ivoa.net>



J.J. Kavelaars (NRC-Canada)  
and G. Bruce Berriman  
(Caltech/IPAC-NExSci)

IVOA Executive Committee



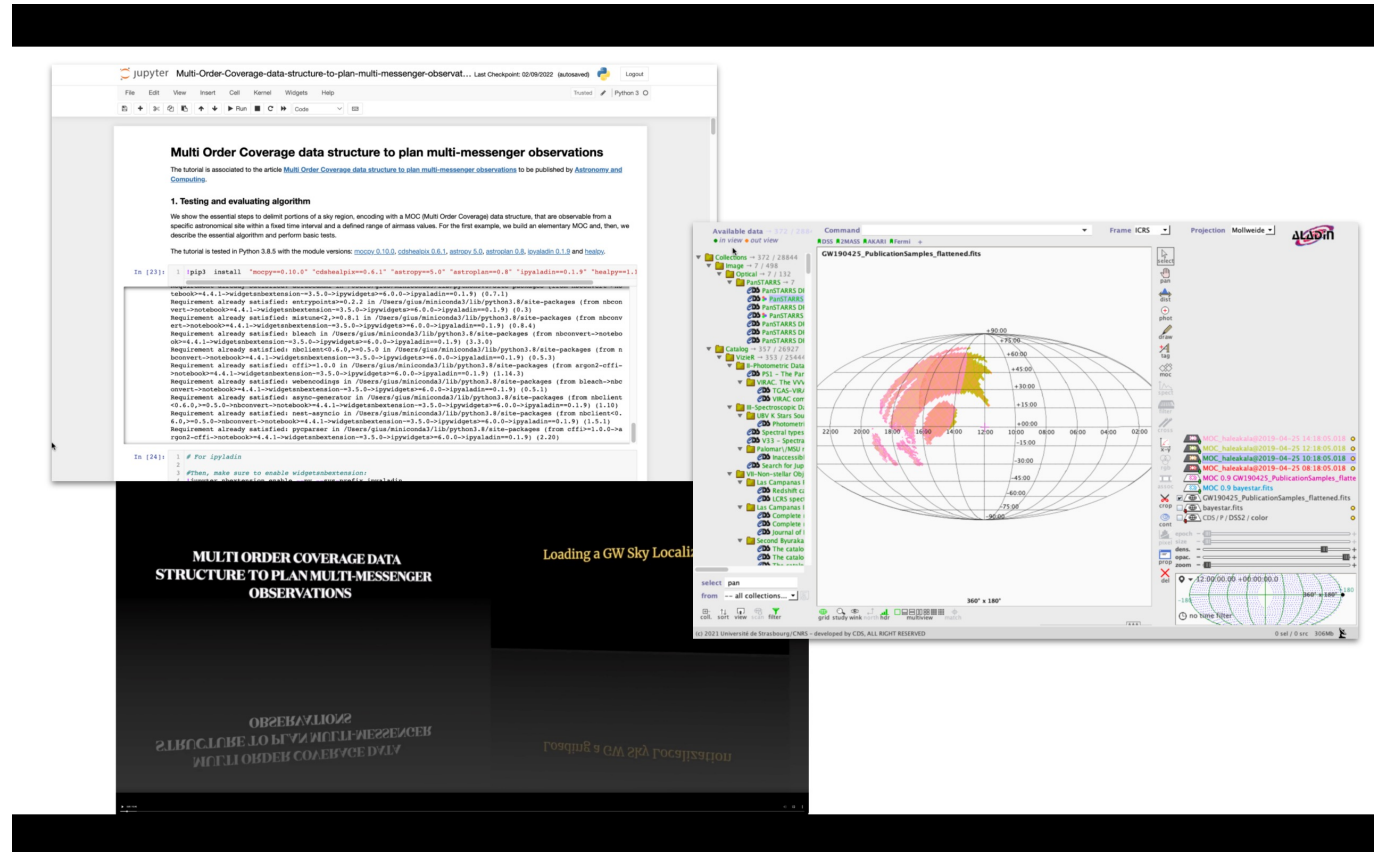


# What Is The Virtual Observatory?

- “A multi-wavelength digital sky that can be searched, visualized, and analyzed in new and innovative ways.” - *Pepi Fabbiano*
- The VO is an ecosystem of interoperating tools and services that enable multidata set analysis.
- Data discovery and access protocols enable the Virtual Observatory to be built. They form the plumbing!

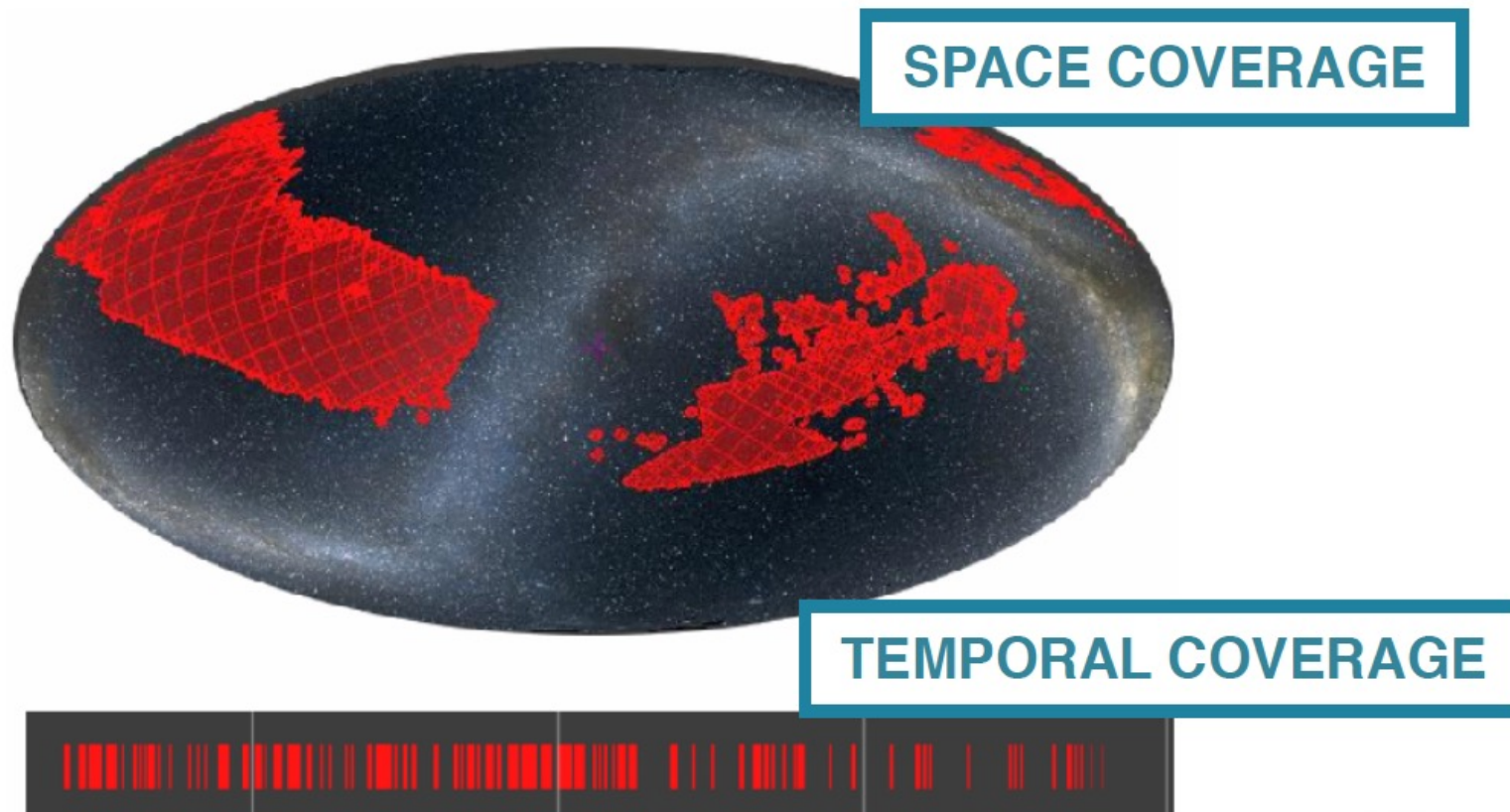
# Aladin (CDS)

- Interactive SkyAtlas
- One of the first applications to adopt VO-standards
- Images surveys, catalog overlays
- Progressive visualization (“multi-order coverage maps”)
  - Recent VO standard



# Aladin and Multi Messenger Astronomy

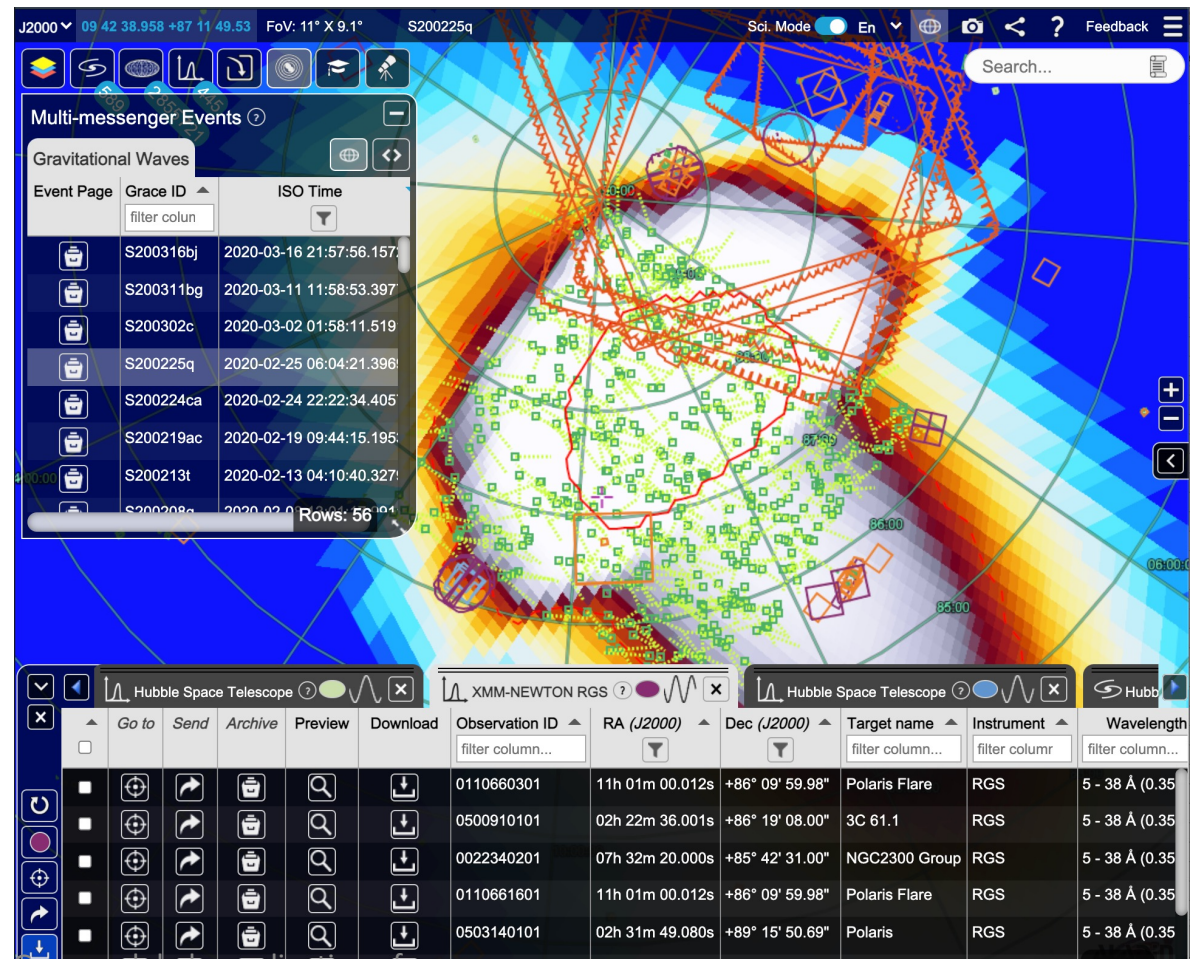
- Generalisation of MOC to integrate the time
- Same principles for the space as for MOC1.0
- Time discretisation based on JD





# ESASky

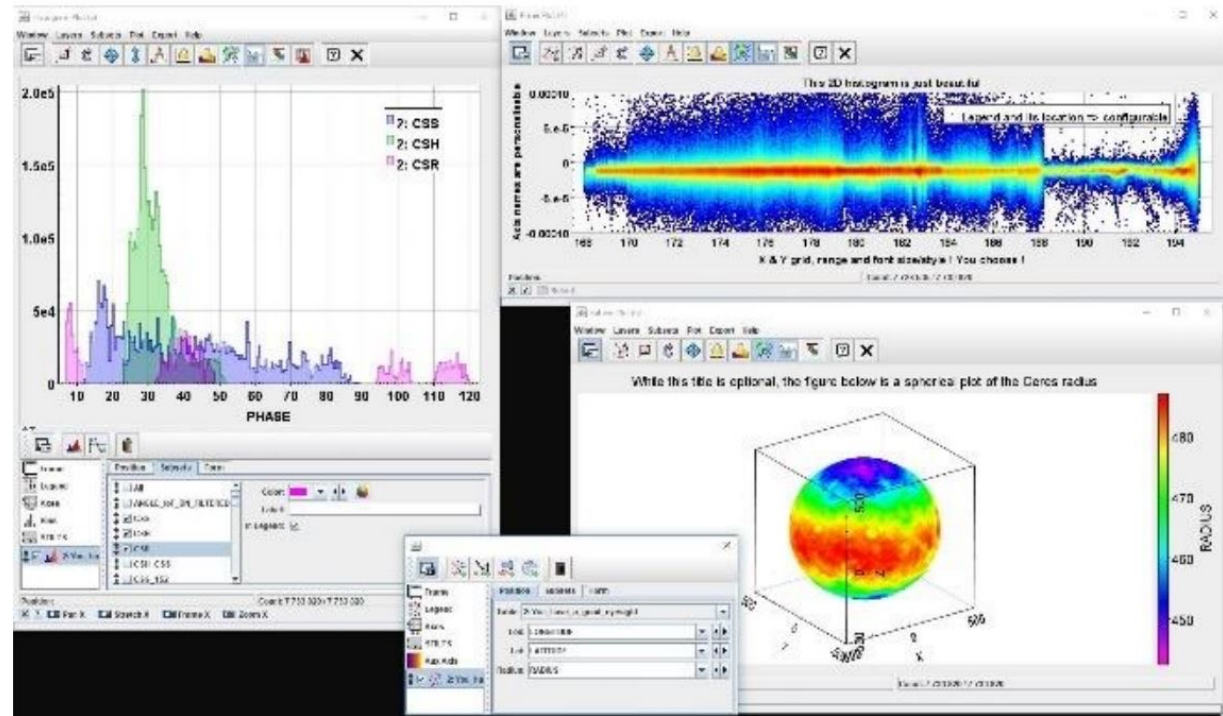
- Explore the entire electromagnetic spectrum
- Missions include HST, Chandra, Spitzer, PAnStarrs...
- Access to scientific publications
- **New:** Multi-messenger astronomy gravitational wave (GW) events
  - Shows probability maps on the sky to aid searches for EM counterparts
- Coming: IceCube neutrino footprint



# TOPCAT: Tool for Operations on Catalogues And Tables



- Interactive graphical viewer and editor for tabular data from multiple sources.
- Optimized for large - *multi-million row, lots of columns* - **tables**.
- Open source, Java desktop application.
- Built to access access data from VO-compliant archives.
  - 120 Table Access service
  - 340 image access services
  - 130 spectral access services
  - 7238 catalog cone searches







P. J. Quinn · K. M. Górski  
Editors

European  
Southern  
Observatory

# TOWARD AN INTERNATIONAL VIRTUAL OBSERVATORY



IVOA Interoperability Meeting October 2022

Springer

Formally founded in 2002 at the conference  
“Toward an International Virtual Observatory”  
(Quinn and Gorski 2004). Garching, Germany.



# The International Virtual Observatory Alliance

<https://ivoa.net>

- Founding partners:
  - Astrophysical Virtual Observatory (AVO, ESO)
  - AstroGrid (UK)
  - National Virtual Observatory (USA)
- Membership open to nationally-funded VO-projects and international organizations.
  - See Hanisch et al (2010)  
<https://www.ivoa.net/documents/latest/IVOAParticipation.html>
- By 2004, there were 15 partners, and in 2022, there are 24.
  - Latest members: SKAO, Kazakhstan VO
- Partners seek funding from their national funding agencies





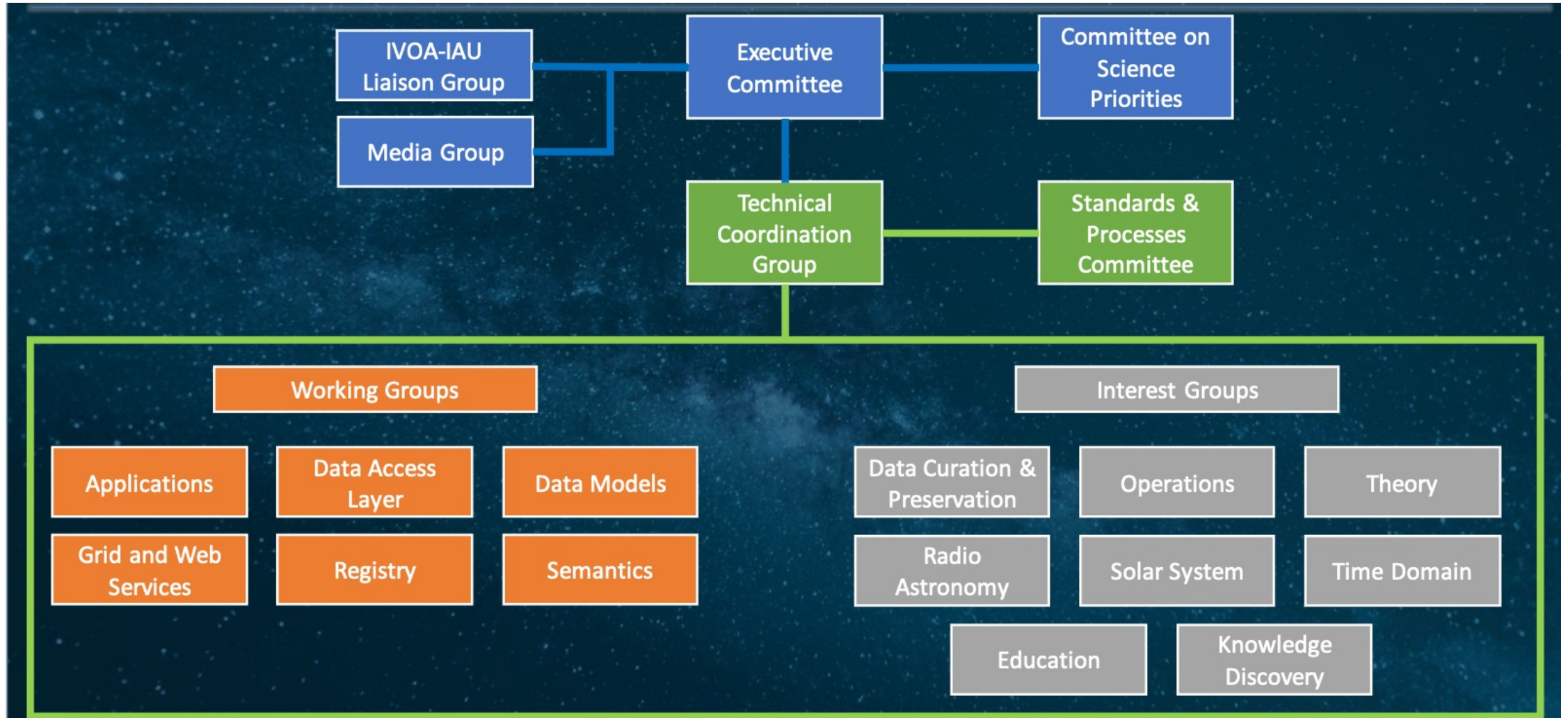
# The IVOA's Mission

“To facilitate the international coordination and collaboration necessary for the development and deployment of the tools, systems, and organizational structures necessary to enable the international utilization of astronomical archives **as an integrated and interoperating Virtual Observatory.**”

-As formulated at “Towards an International Virtual Observatory”

**The IVOA defines the protocols that make the VO happen.**

# Organization of the IVOA



# Organization of the IVOA

- The IVOA patterned itself after the World-Wide Web Consortium (W3C):
  - Adopted its process for the development of standards (Working Drafts ! -> Proposed Recommendations -> Recommendations)
  - Standards documents developed by a set of working groups.
- Two Interoperability Workshops each year.





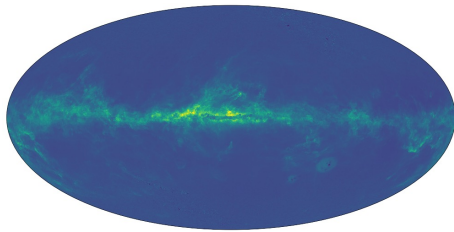
# IVOA Standards Are Implemented Worldwide

- VO standards are now built into the architectures of most of the world's astronomy archives and are considered fundamental to interoperability and data discovery.
  - NASA archives, SAO, ESA, CDS, Australian VO..
- New missions actively building the VO into their infrastructure
  - Rubin, Euclid, ....

# Gaia and the VO

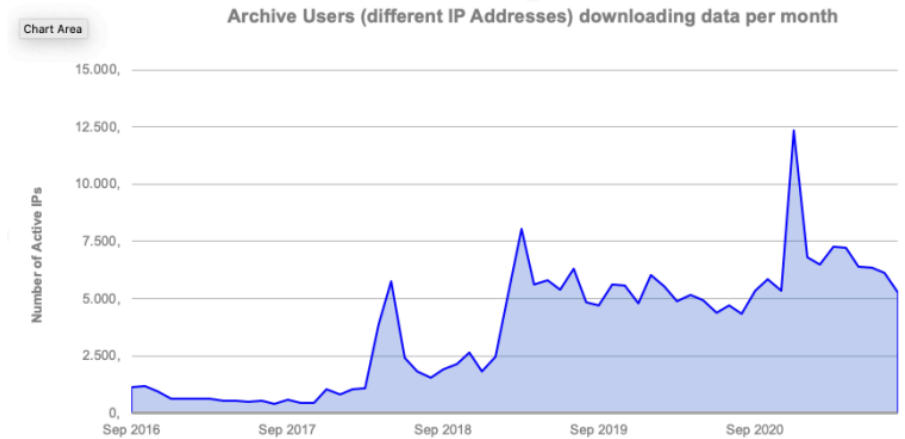


- Gaia data for all releases since 2016 are accessed only through VO services.
- DR3 released on 6/13/2022 contains 1.6 billion sources
- 9828 papers (as of Sept 11 2023)

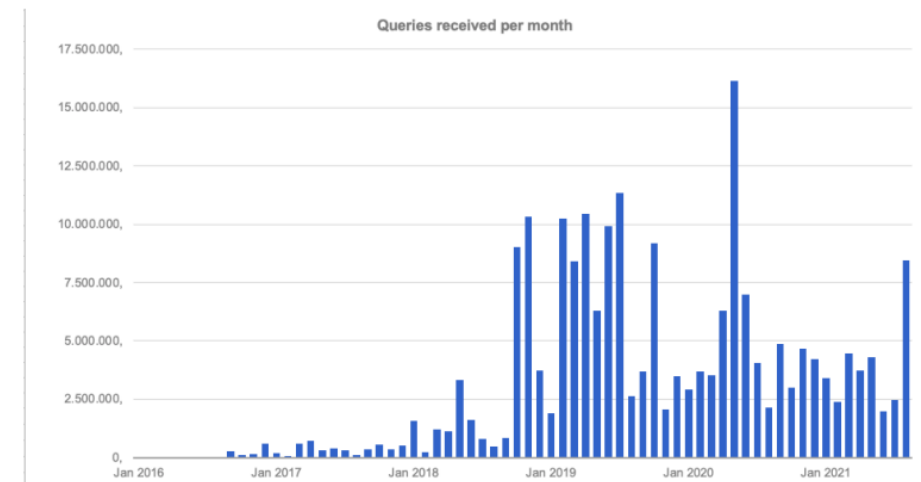


*All-sky map (Hammer projection) in the JWST NIRCам photometric system. The plot shows the median of the color  $F070W - F090W$  in each HEALPix (level=7), as measured from the Gaia XP spectra using synthetic photometry. Image credits: ESA/Gaia/DPAC - [CC BY-SA 3.0 IGO](https://creativecommons.org/licenses/by-sa/3.0/).*

## 5.2 TAP Interface

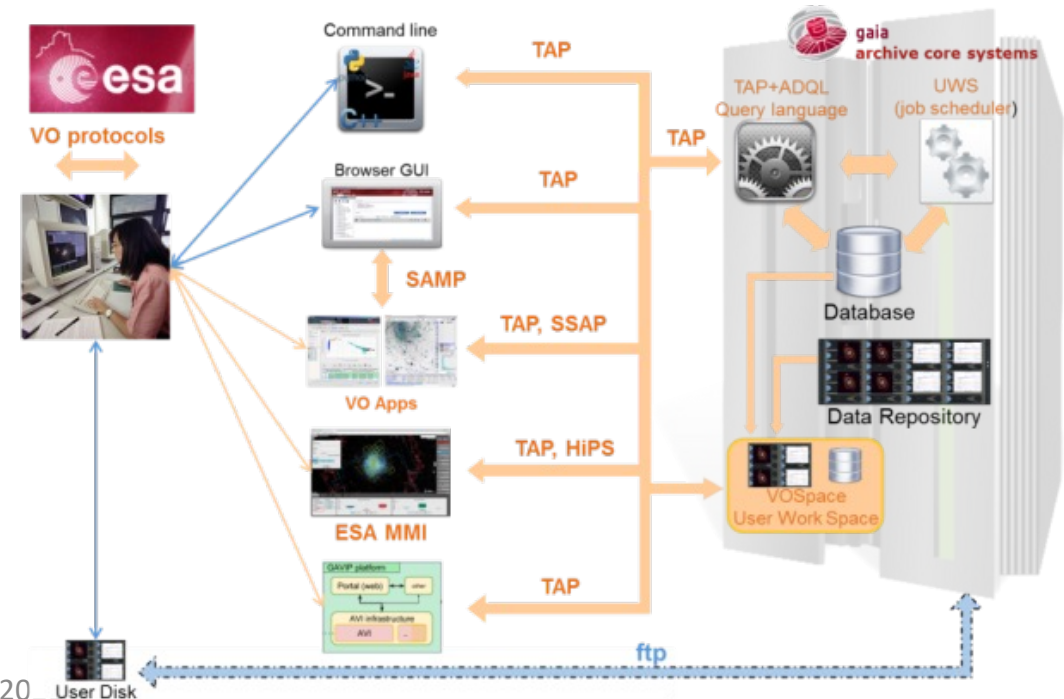
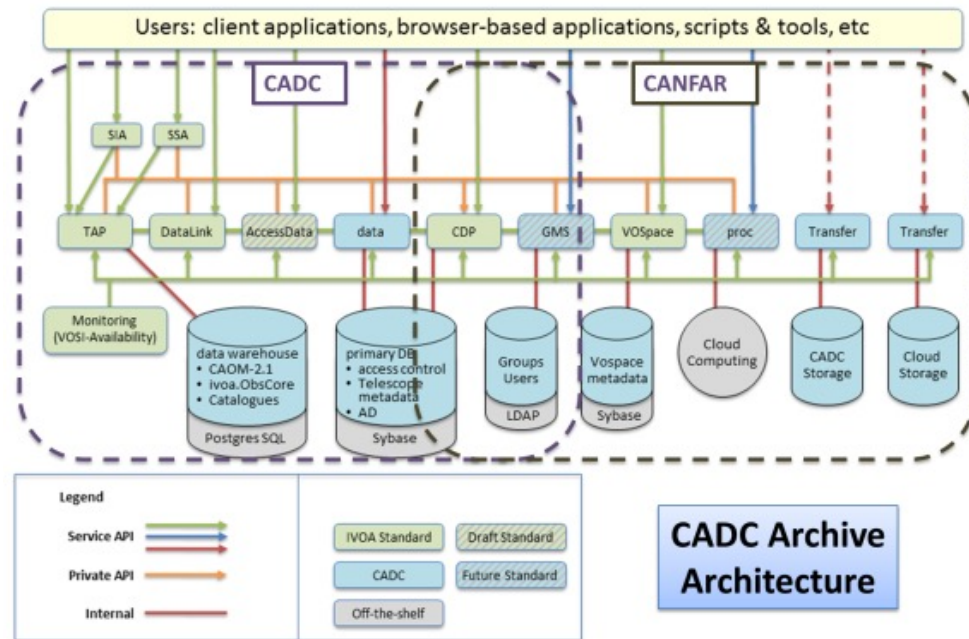


Active user: Different IP addresses downloading science-level data (query results) from TAP, ConeSearch interfaces. Bulk download is excluded.



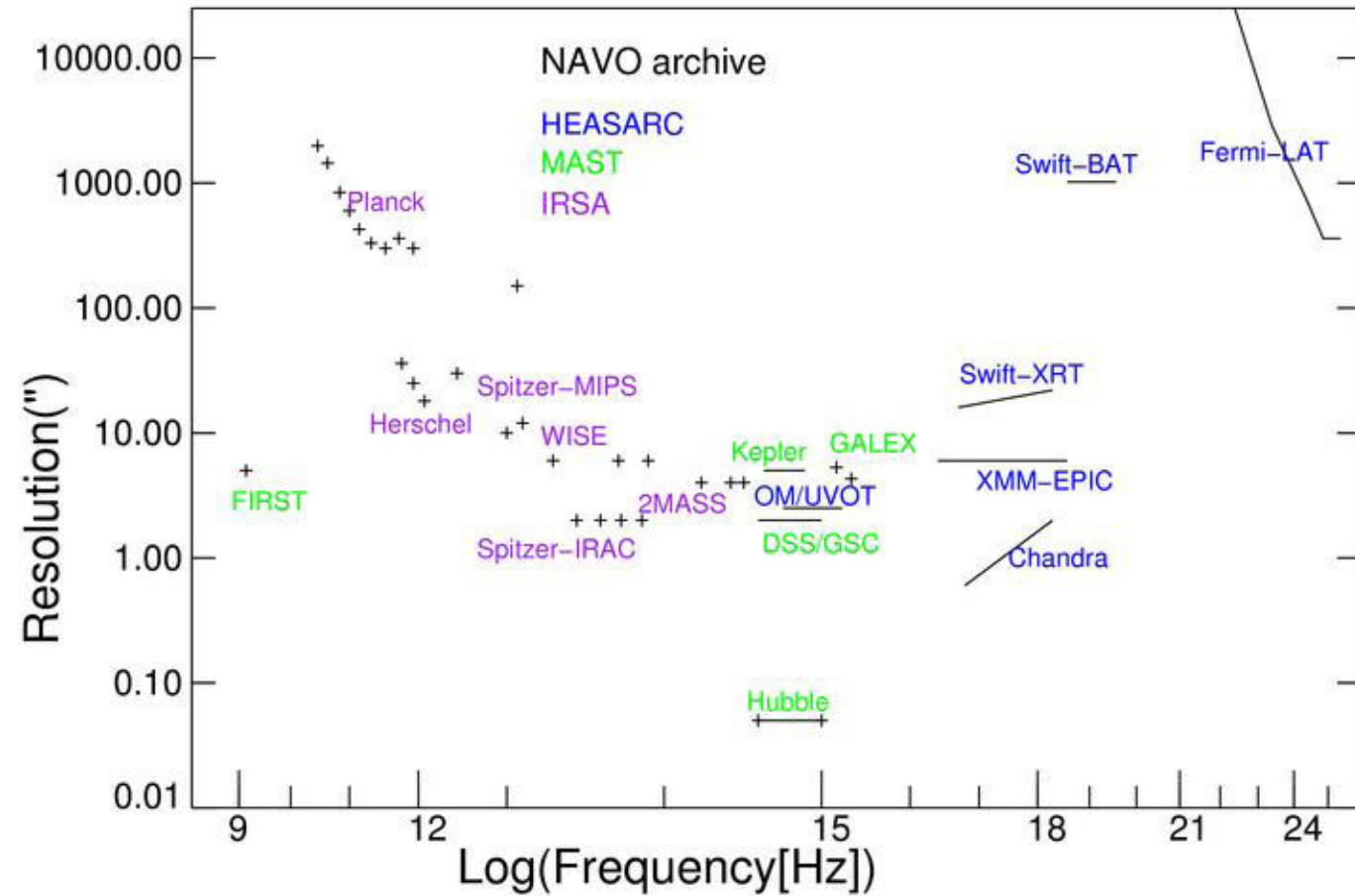
# IVOA in the Community

- VO-ready infrastructure built-in astronomical data centers
  - CADC, Gaia, Euclid, ...
  - Data (file & database) access and User Work Space (VOspace)



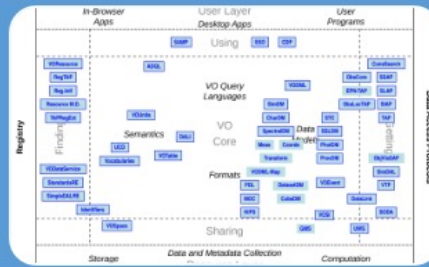


NASA archives have implemented IVOA standards across distributed archives of heterogeneous data over 15 decades of frequency



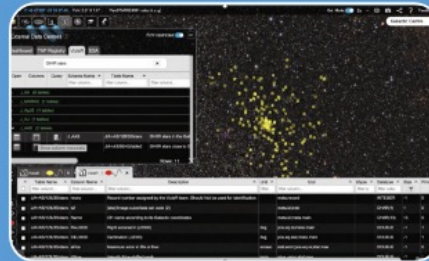
On average, NAVO services respond to nearly 3 queries per second

# Vision of the International Virtual Observatory Alliance



## Develop a FAIR data management framework for astronomy

- Interoperability standards (VO framework) amongst astronomical (ground and space based) archives
- Publishing tools for data centres



## Enable new science through the VO

- Multi wavelength science, combining datasets from multiple sources
- Data discovery and data access tools
- Data analysis and visualization tools



## World wide collaboration amongst astronomical VO projects

- Created in 2002, 22 projects today
- No formal funding, nationally funded projects
- Diversity makes IVOA's richness

C. Arviset:

<https://wiki.ivoa.net/internal/IVOA/InterOpMay2023/20230512-CA-IVOAExecClosingRemarks-Bologna.pdf>

# Survey of Data Providers 2022

□ A total of 45 responses! Thank you all!

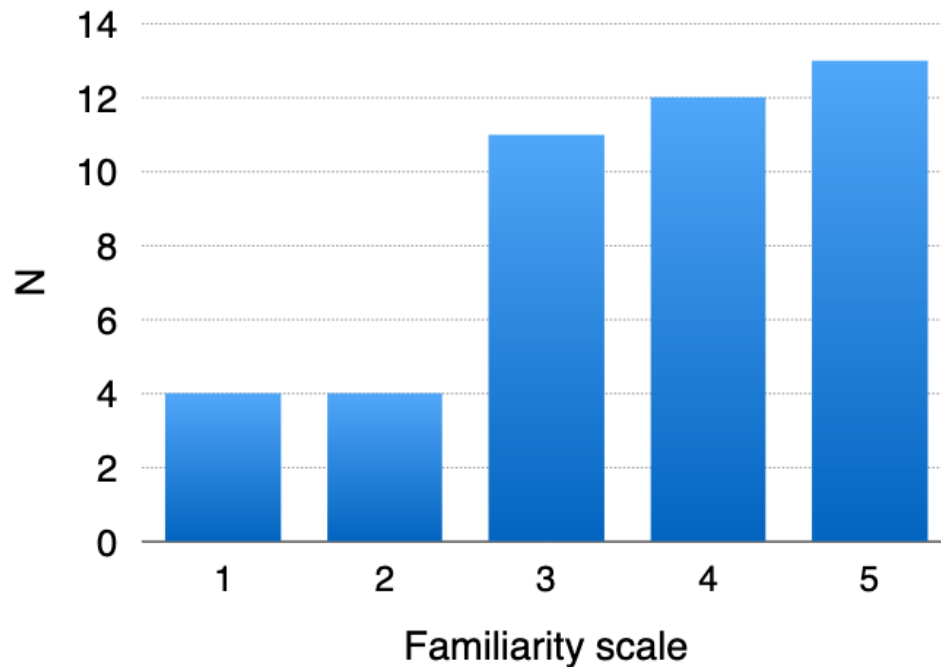


**Goal: Identify priorities and understand how we can provide best service to the community**

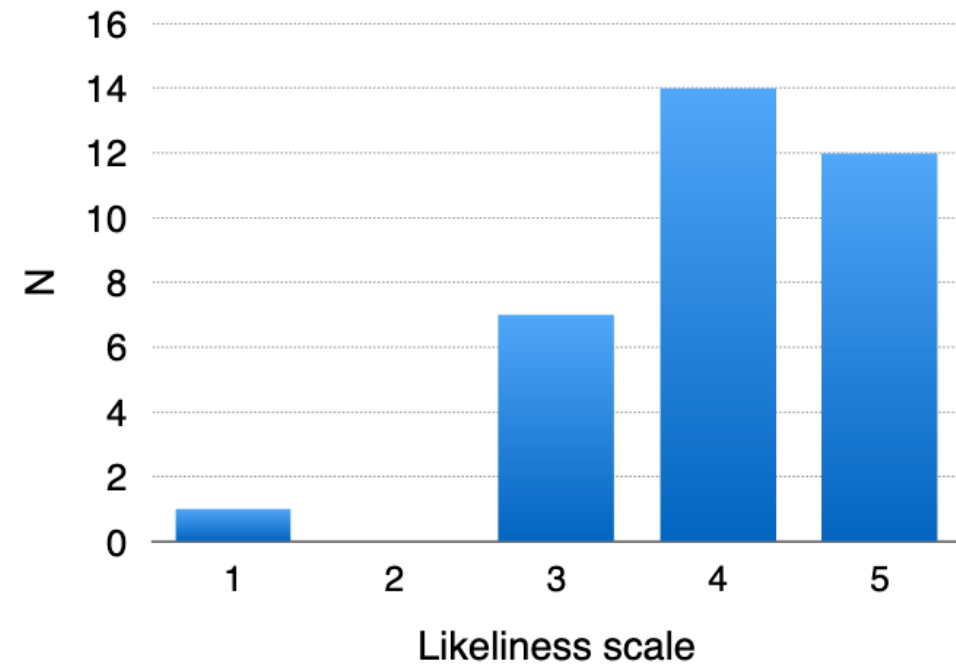


# Data Usage and Interoperability

- How familiar are you with the VO and the IVOA?



- How likely is it that your project will use interoperability IVOA standards?



Interoperability Requirement for 60% of missions

IAU Executive Committee Working Group : global coordination of  
ground and space

# What Did We Learn?

- 2/3 of the projects deal with observations, 1/3 with simulations or both
- Each project delivers a wide variety of data product types.
- Many projects have both public and private access (45%) requiring authenticated access
- Access to the data is expected to be done in various ways but mostly through project web interface followed by VO clients.
- IVOA needs to ensure data providers can get started.

# Community Engagement: Radio Astronomy

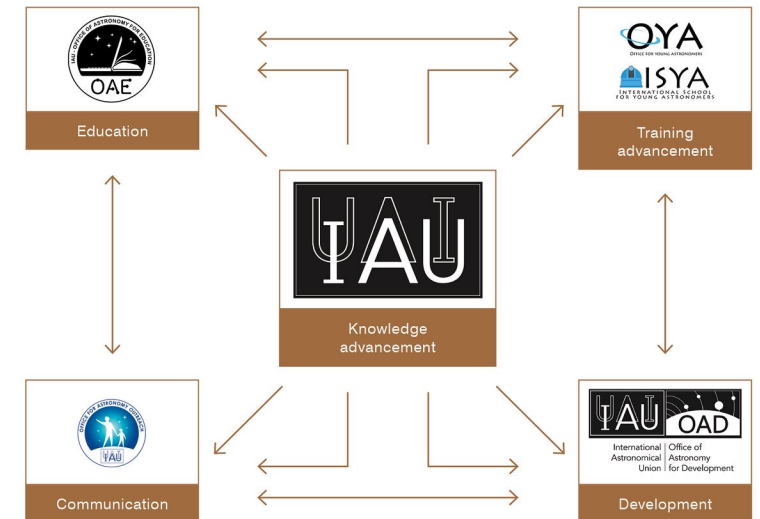
- The Square Kilometer Array Observatory (SKAO) joined the IVOA as a full member in 2021
- Radio Astronomy Interest Group est. late 2019
  - Members represent major radio astronomy projects: MWA, ALMA, ASTRON (LOFAR, APERTIF, WSRT, ...)
  - Active in extending IVOA protocols applicable to radio astronomy e.g. working with the Time Domain IG to establish protocols for time domain data/MMA





# Community Engagement and the IAU

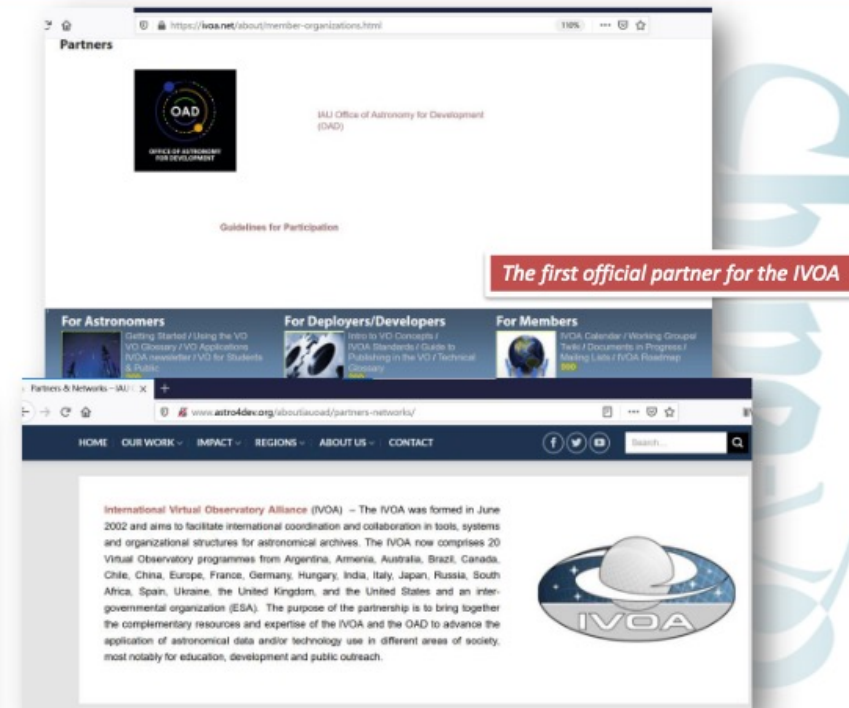
- A VO Functional Working Group established within Division B
  - Bruce Berriman (Chair).
- Active participation in IAU General Assembly 2022
- Participation planned in IAU GA 2024 (Cape Town)
  - VO WG has been asked to co-organize and present and to co-organize an Open Science Day
- Educational activities
  - MoU signed between IVOA and IAU-Office of Astronomy for Development (OAD) (<https://www.astro4dev.org/>).



“The IAU's mission is to promote and safeguard astronomy in all its aspects (including research, communication, education and development) through international cooperation.”  
<https://www.iau.org/>

# Community Engagement and the IAU.

## Collaboration between IVOA and IAU OAD



# Next meeting: Australia, May 2024

<https://rds.org.au/events/ivoa-2024/>

## IVOA 2024

**Sunday 19th - Friday 24th May**

The IVOA May 2024 Interoperability Meeting will be organised by Australian Astronomical Optics and held at Macquarie University Wallumattagal Campus (the main campus), located 15 kilometres from Sydney's city centre, in one of the largest business and technology precincts in the Southern Hemisphere.



**MACQUARIE**  
University  
SYDNEY • AUSTRALIA



NEED HELP?

**Contact Us**

# BACKUP SLIDES

- Time Domain
- Helio Physics
- Meta Data



# Time Domain Astronomy and the IVOA

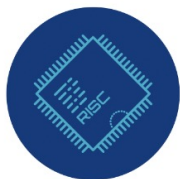
“Standards are critical to ensuring that heterogeneous nodes in the transient/multi-messenger ecosystem can communicate efficiently and effectively. **We strongly recommend that the transient/multi-messenger community work with the International Virtual Observatory Alliance (IVOA) to build its standards ... it is critical to have involvement and support of the community.**”

*Cenko et al. (2020) “International Coordination of Multi-Messenger Transient Observations in the 2020s and Beyond: Kavli-IAU White Paper” Convened by the IAU Executive Committee Working Group on Global Coordination of Ground and Space Astrophysics.*

- “All priority science areas require multiwavelength observations with highly capable facilities

- High contrast imaging
- High spatial resolution
- High spectral resolution
- High temporal resolution
- High cadence
- High performance computing
- High scalability

#### Astronet Roadmap



Computing; big data, HPC and data infrastructure



Origin and evolution of the Universe



Formation and evolution of galaxies



Formation and evolution of stars



Formation and evolution of planetary systems



The solar system and the conditions for life



Extreme Astrophysics



Astronomy and society

## Sources of Science Drivers for the IVOA

- Decadal survey
  - <https://nap.nationalacademies.org/catalog/26141/pathways-to-discovery-in-astronomy-and-astrophysics-for-the-2020s>
- Astronet roadmap
  - [https://www.astronet-eu.org/wp-content/uploads/2023/05/Astronet\\_RoadMap2022-2035\\_Interactive.pdf](https://www.astronet-eu.org/wp-content/uploads/2023/05/Astronet_RoadMap2022-2035_Interactive.pdf)

# Questions we need to grapple with

Courtesy: Ada Nebot

- **Next generation missions coming up**
- Which are needed upgrades to protocols to keep up with the needs?
  - Different formats from different communities PSRFITS, GADF,...
  - Different data types >> **Data cubes &** >> **Spectra** - Are we ready for the exploration, visualisation and analysis?
  - Transient phenomena **alert** distribution is evolving, implications?
  - Extend protocols **from discovery & access to data manipulation?**
  - Can VO protocols & formats help **ML and AI algorithms?**
  - What is the role of **the VO in the Cloud & Science Platforms?**
  - **Interoperability of science platforms?**
  - Reproducibility & reusability? What is the role of the **provenance data model in this context?**

# Accomplishments

Courtesy: Ada Nebot

## Heliophysics and the IVOA

### IHDEA (International Heliophysics Data Environment Alliance)

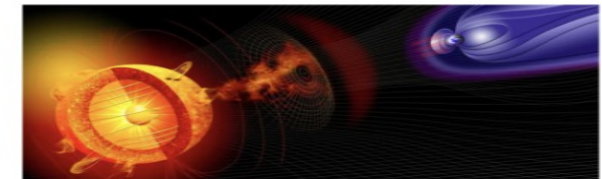
- Oct 2023: DASH+IHDEA meeting
- Discussed about tighter links with the IVOA. Identified topics:
  - Resource discovery:
    - How to reuse/inspire from IVOA recommendations to improve the IHDEA/SPASE registry?
    - Use of EPNTAP as a resource discovery interface?
  - Semantics:
    - Use the IVOA Semantics vocabularies as a common source of terms? (e.g.: reference frames)
  - Time Domain:
    - Improve VOEvent for storing heliophysics event?
    - Integrate HAPI\* in IVOA framework? See TDIG talk
  - Access:
    - Push for more adoption of TAP



<https://dash.heliophysics.net/>



<https://ihdea.net/>



HAPI\* = Heliophysics API (simple API to access time-series). <https://github.com/hapi-server>

CSP Status

7



# IVOA Goals

Courtesy: Ada Nebot

- Driven by cloud and science platform initiatives.
  - ➡ how to update SIA to return cloud and/or on-prem pointers
  - ➡ how to use cloud-friendly Parquet format for large catalogs in an IVOA-friendly way
- Driven by new missions providing >> spectra
  - ➡ Updates to extend the spectral data model to cope with use cases that involve hundreds of millions of spectra expected from Euclid and SPHEREx.
- Driven by Radio data
  - ➡ Updates of Obscore extensions. See Radio session

# It's all about the metadata!



**“The FAIR Guiding Principles for scientific data management and stewardship”.** Wilkinson et al 2016. *Sci Data* **3**, 160018 (2016).  
<https://doi.org/10.1038/sdata.2016.18>

- To a large degree, implementing IVOA standards goes a long way to implementing FAIR principles.
- “FAIR standards for astronomical data.” 2022. S. O’Toole and J. Tocknell.  
<https://arxiv.org/pdf/2203.10710.pdf>. To appear in Proc. ADASS XXXI.

# The IVOA and Persistent Identifiers

## Basic Definition

Persistent identifiers (PIDs) are long-lasting references to digital objects of various types

## US Government Definition

- A digital identifier that is globally unique, persistent, ***machine resolvable and processable, and has an associated metadata schema.***


<https://www.whitehouse.gov/wp-content/uploads/2022/08/08-2022-OSTP-Public-Access-Memo.pdf>

# Education and Outreach

TUTORIALS	DESCRIPTION	Link
<a href="#">Abell 1656: The Coma Cluster of Galaxies</a>	This tutorial uses the advanced VO functionalities of Aladin (interactive sky atlas), TOPCAT (tools to work on catalogs) and Cassis (interactive spectrum analyzer) to study interactively the Coma cluster of galaxies. The user can visualize the Coma cluster of galaxies and build a subset of these galaxies with Aladin. With TOPCAT, they can analyze this subset. Finally, they can study an HST power spectrum with Cassis.	<a href="#">Jupyter Notebook</a>
<a href="#">Discovery of Brown Dwarfs mining the 2MASS and SDSS databases</a>	This tutorial uses the advanced VO functionalities of Aladin (interactive sky atlas) to find brown dwarfs in the 2MASS and SDSS surveys. The user learns about the filtering, cross-matching and visualization functions, the implementation of scripts in Aladin and many more Aladin features to identify brown dwarfs in these surveys. This tutorial has been last updated for the first ESCAPE "Science with interoperable data school", previous versions of this tutorial repeated the same discovery steps with TOPCAT and STILTS. For this tutorial you will need a <a href="#">parameter</a> and <a href="#">script</a> file.	<a href="#">Jupyter Notebook</a>
<a href="#">The CDS tutorial</a>	This tutorial describes the basis of the VO program hosted at CDS. The three major VO programs are described: SIMBAD (astronomical database), VizieR (catalog service) and Aladin (interactive sky atlas). The user gets familiar with the programs while 1) searching for the galaxy NGC4039 through the CDS portal to get direct access to SIMBAD, VizieR and Aladin, 2) comparing the sky coverage between SDSS and GALEX surveys using Aladin and 3) selecting interacting galaxies with Aladin.	<a href="#">Jupyter Notebook</a>
<a href="#">Determination of stellar physical parameters using VOSA</a>	This tutorial uses the advanced VO functionalities of VOSA (VO Sed Analyzer) and TOPCAT to determine empirically the masses and radii of stars surrounded by planets. The user needs to register to get access to the functionalities of VOSA (online tool). They can then upload a list of objects to study, build their SEDs and analyze them (by fitting models). Using the interoperability between VOSA and TOPCAT, the user can compare the empirical values obtained with VOSA to those published in papers.	
<a href="#">Accessing and cross matching big datasets with ADQL</a>	This tutorial allows the user to get familiar with ADQL (Astronomical Data Query Language) and TAP (Table Access Protocol) through using GAIA data. ADQL and TAP are widely used in VOs to handle large datasets that cannot be handled locally.	
<a href="#">Electromagnetic follow-up of gravitational-wave event</a>	This online tutorial uses mostly Aladin functionalities to locate the sources of latest gravitational wave events on the sky	
<a href="#">Exploring Gaia with TopCAT and STILTS</a>	This tutorial uses TOPCAT and STILTS to study the Pleiades open star cluster. The user starts with getting TGAS data for the Pleiades and identifies its as a comoving subset. In a second step, the user matches HST data with Gaia observations using the interoperability of TOPCAT with VizieR to access the catalogs. The cross-match is refined using a color-magnitude diagram. The user can also use the TAP (Table Access Protocol) service of TOPCAT to run scripts for Gaia data. Finally, the user can upload the full TGAS catalog and investigate it with STILTS.	
<a href="#">Advanced usage of HiPS and MOCs</a>	This is a hands-on tutorial demonstrating an advanced usage of Hierarchical Progressive Surveys (HiPS) and Multi-Order Coverage (MOC) maps in Aladin. Using this document, you will learn how to handle a problem like : I have an image survey. I would like to select regions in my observations that are above a given threshold in another survey (e.g. at low extinction), retrieve objects from very large catalogs (e.g. Gaia + WISE) in these non-trivial shapes and not-necessarily-connected regions, and combine them to visualise some quantiles (e.g. color magnitude diagram).	<a href="#">Jupyter Notebook</a>
<a href="#">Classifying the SEDs of Herbig Ae/Be stars</a>	Herbig Ae/Be stars are 2-8 solar mass. These stars show Balmer emission lines in their stellar spectrum and infrared excess due to circumstellar dust. They roughly fall into two groups: Group I sources have a relatively strong far-IR flux. Group II sources show a similar near-IR excess as group I sources but their flux falls off strongly towards the far-IR. In this tutorial, you will learn how to use VO tools and services to access observed photometric SEDs and spectra in the near and far infrared of different stellar objects. You will compare the stars and classified them.	
<a href="#">Multi-instrument, multi-wavelength study of high energy sources with the virtual Observatory</a>	This tutorial makes extensive use of the cross-matching and selection (based on criteria) functionalities of the VO tools to study high energy sources observed at different photon energy bands and with various instruments. The user queries SIMBAD to get HESS sources and overlays them on a Fermi LAT image in Aladin. They then cross-match HESS sources with the Fermi LAT catalog that they download from VizieR via its interoperability with TOPCAT. Applying selection criteria with TOPCAT functionalities, they can identify different classes of objects in a color-color diagram to finally get SEDs for the objects of interest.	<a href="#">Jupyter Notebook</a>
<a href="#">Handling gravitational-wave sky maps for EM-followUP observations</a>	This tutorial uses the functionalities of Aladin to visualize probability sky maps. It also makes extensive use of the MOC (Multi-Order Coverage) capabilities of Aladin to query a given region of the sky and access the catalogs with information in that region via the interoperability with VizieR. Finally the additional interoperability with TOPCAT permits sending the data available in that region to the latter for further studies.	
<a href="#">Determination of stellar physical parameters using SPECFLOW</a>	This tutorial provides an overview of the usage of SPECFLOW also in combination with other VO tools like CASSIS. The goal of the tutorials is the evaluation of physical properties of the stars HD232862 and VEGA.	

GRITS October 2021

## EuroVO for education








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**Note:** our project depends on your appreciation. If you found our products useful, please reference it in your work, send us an email or like us on Facebook. [Like](#)

### Download usage examples

Usage examples aim at familiarizing the user with Aladin and Stellarium and at stimulating further interest and activities in astronomy. Usage examples are in the form of pedagogic modules consisting of two main parts. The first part presents a typical astronomical problem with a short introduction and a description of the solution found by astronomers, or, in some cases, an expanded treatment of the problem. The second part is a step-by-step guide to the commands needed to reach the solution of the problem with Aladin or Stellarium. Some of our usage examples include exercises that are proposed for teachers' activities in the classroom. Solutions are provided separately.

*Astronomical Infrastructure for Data Access*

- The sky - basic**   
Within this use case you discover the celestial coordinates allowing you to point and/or find a given star in the sky. You also learn how to use coordinate systems in order to learn the effects of Earth's rotation and revolution on the celestial sphere. Special topics are constellations and light pollution, both important for a basic appreciation of the night sky.
- The stars - intermediate**   
Within this use case you discover the basic observational parameters of stars, color and magnitude. These observational parameters are counterparts of the main physical parameters temperature and luminosity. By selecting stars on the sky you build the Hertzsprung-Russell diagram that shows the relation between color and magnitude, a milestone in the history of our understanding of how stars work and evolve.
- The shape of galaxies - basic**   
Within this use case you discover the shapes of galaxies and their classification according to the Hubble diagram. You are offered sequences of galaxies with different morphologies and are asked to order them. The morphological classification of galaxies is still in use even if we have discovered that the Hubble diagram "per se" has no direct physical or evolutionary meaning. Besides introducing the main shapes of galaxies, the use case offer a demonstration of the classification process, a fundamental tool of astronomers.  
\* download a galaxy set: [hubble\\_1.zip](#), [hubble\\_2.zip](#), [hubble\\_3.zip](#), [hubble\\_4.zip](#)
- The Pleiades open cluster - advanced**   
Within this use case you recognize a physical association of stars close in space as opposed to a superposition created by projection effects of stars very far one from the others. The key measure is distance derived from parallax. With the true members of the association (open cluster) you create a Hertzsprung-Russell diagram as in use case 2. The Hertzsprung-Russell diagram of stellar clusters is very important because of the low noise of few unrelated stars.
- Proper motion of the Barnard's star - intermediate**   
Within this case you learn that stars that seem "fixed" on the sky may actually move, even if their motion is so slow for the naked eye to be undetectable. You compare two photographs of the Barnard's Star taken several years apart and will be able to estimate its displacement on the sky. Your estimate will be very close to actual measurements.

### latest use cases and software

**New Stellarium 0.20.4.**  
/ February 15, 2021 /  
[New release of Stellarium Software / ... /](#)

**New usecase: The disk of the Milky Way.**  
/ April 2, 2018 /  
[New usecase on shape and properties of the Milky Way / ... /](#)

**New usecase: Stellarium for beginners.**  
/ March 10, 2017 /  
[New usecase on basic features of Stellarium and simple examples on how to use it / ... /](#)

[http://vo-for-education.oats.inaf.it/index\\_eng.html](http://vo-for-education.oats.inaf.it/index_eng.html)



# Stay connected! Get involved!

- IVOA Newsletter.  
<https://www.ivoa.net/newsletter/index.html>

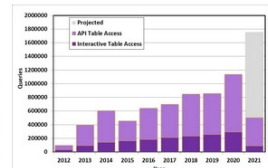


## VO APPLICATIONS AND IMPLEMENTATION HIGHLIGHTS

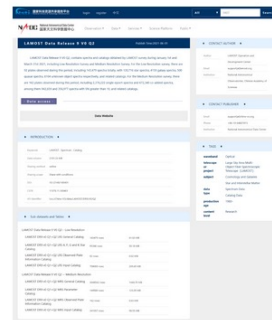
### TAP Service at the NASA Exoplanet Archive

Bruce Berriman

The NASA Exoplanet Archive, operated by the NASA Exoplanet Science Institute at IPAC, has over the past 18 months redesigned its infrastructure to make the data more standardized, easier to access, more complete, and better reflect the scientific progress of the field of exoplanetary astrophysics. As part of this effort, the Exoplanet Archive released new and more comprehensive tables that were underpinned by Python-based nexsciTAP server (<https://github.com/Caltech-IPAC/nexsciTAP>). With the release of the new tables atop the new TAP services in 2020, the NASA Exoplanet Archive saw a noticeable increase in access of the tables by the community. The NASA Exoplanet Archive is now in the process of making all its tables TAP compliant.



Growth in usage of the NASA Exoplanet Archive over time. The TAP services were released in 2020.



### VO standards-based Metadata Management and Data Submission System of NADC

Yihan Tao

The National Astronomical Data Center (NADC) of China has developed a metadata management and data submission system. Data preservation for research project is one of the major responsibilities for NADC. The system is aimed at supporting the data submission process of astronomical projects, including the submission and review of metadata and data. With the system, data administrators can also curate a published data catalogue and manage the metadata. The metadata standard employed in the system is consistent with and extended from the VO standards-Resource Metadata for the Virtual Observatory Version 1.12 and IVOA Observation Data Model Core Components and its Implementation in the Table Access Protocol. In order to describe and filter the dataset by types, a multifaceted taxonomy of waveband, telescope/project, subject, data product type, production age, process level, content type and content level is adopted in the system and displayed as tags.

